CHAPTER 38
DESIGNING FOR RADIATION PROTECTION

RADIOGRAPHIC PROTECTION FEATURES

Protective X-ray Tube Housing

- It must be contained within protective housing
- It reduces leakage radiation

Leakage radiation must be less than 100 mR/hr at a distance of 1 m from the protective housing!

Control Panel

- It must indicate the condition of exposure
- It must positively indicate when the x-ray tube is energized
  - kVp & mA indicators

X-ray beam on must be positively & clearly indicated to the radiologic technologist!

Source-to-Image Receptor Distance Indicator

- It must be provided
  - Tape measure attached to the tube housing
  - Lasers

The SID indicator must be accurate to within 2% of the indicated SID!

Collimation

- Light-localized, variable-aperture rectangular collimators should be provided
- *Cones & Diaphragms:* for special examination

The x-ray beam & the light beam must coincide to within 2% of the SID!

Positive-Beam Limitation (PBL)

- Automatic, light-localized, variable-aperture collimators

The PBL must be accurate to within 2% of SID!

Beam Alignment

- Each radiographic tube should be provided with a mechanism
  - *Purpose:* to ensure proper alignment of the x-ray beam & the IR

Filtration

- *Total Filtration:*
  - 2.5 mm Al – operated above 70 kVp
  - 1.5 mm Al – operated b/n 50-70 kVp
  - 0.5 mm Al – operated below 50 kVp
- *HVL:* it measures filtration

Mammography

- *Total Filtration:* 30 μm Mo or 60 μm Rh

Reproducibility

- For any radiographic technique, the output radiation intensity should be constant form one exposure to another

The variation in x-ray intensity should not exceed 5%!

Linearity

- Ability of a radiographic unit to produce constant radiation output for various combinations of mA & exposure time
- *Radiation Intensity:* mR/mAs

The maximum acceptable variation in linearity is 10% from one mA station to an adjacent mA station!

Operator Shield

- RT may be in the exposure room during exposure, but only if protective apparel is worn
- *Exposure Control:* fixed, not a long cord

Mobile X-ray Imaging System

- *Lead Apron:* should be assigned
- *Exposure Switch:* at least 2 m from x-ray tube during exposure

CHAPTER 38
DESIGNING FOR RADIATION PROTECTION

FLUOROSCOPIC PROTECTION FEATURES

Source-to-Skin Distance
- *Increased SSD:* reduces entrance skin exposure (ESE)
- *Stationary Fluoroscopes:* not less than 38 cm
- *Mobile Fluoroscopes:* less than 30 cm

Primary Protective Barrier
- *Fluoroscopic IR Assembly:*
  - It serves as a primary protective barrier
  - It must be 2 mm Pb equivalent
  - It must be coupled with the x-ray tube & interlocked

Filtration
- Total Filtration: 2.5 mm Al
- HVL should be measured when filtration is unknown

Collimation
- Collimators must be adjusted
  - *Rationale:* unexposed border is visible on the image monitor
- *Automatic Collimators:* unexposed border should be visible at all heights above the tabletop

Exposure Control
- Dead man type
- *Controls:* convetional foot pedal & pressure switch

Bucky Slot Cover
- *Bucky Tray:* moved at the end of the table during fluoroscopy
  - *Result:* leaving a 5 cm opening in the side of the table
    - Covered with 0.25 mm Pb

Protective Curtain
- It should be position between fluoroscopist & patient
- *Equivalent:* 0.25 mm Pb

Cumulative Timer
- It produces an audible sound when the fluoroscopic time has exceeded 5 minutes
- Designed to ensure that the radiologist is aware of the relative beam-on time during each procedure

Dose Area Product (DAP)
- A quantity that reflects not only the dose but also the volume of tissue irradiated
- *Expressed in:* R-cm^2
- Better indicator of risk than dose
- X-ray Beam Intensity
  - *Table Top:* <2.1 R/min (each mA operation at 80 kVp)
  - *No Optional High-Level Control:* <10 R/min
  - *With Optional High-Level Control:* 20 R/min
  - *Cineradiography/Videography:* no limit
- *Increased Field Size:* increases DAP & risk

DESIGN OF PROTECTIVE BARRIERS

Type of Radiation
- Primary Radiation
- Secondary Radiation

Primary Radiation
- The useful beam
- The most intense, hazardous & difficult to shield

Primary Barrier
- Any wall to which the useful beam can be directed
- *Examples:* lead bonded to sheet rock (lb/ft^2) or wood paneling

Secondary Radiation
- Scatter & leakage radiation

Scatter Radiation

- It results when the useful beam intercepts any objects causing some x-rays to be scattered

The intensity of scatter radiation 1 m from the patient is approximately 0.1% of the intensity of the useful beam at the patient!

Patient

- The single most important scattering object

Leakage Radiation

- Radiation emitted from the x-ray tube housing in all directions other than that of the useful beam
- *Limit:* 100 mR/hr at 1 m

Secondary Protective Barrier

- Designed to shield areas from secondary radiation
- Less thick than primary radiation
- *Composition:* gypsum board, glass or lead acrylic
- *Example:* operating console barrier & ceiling

Radiologic technologists receive most of their occupational radiation exposure during fluoroscopy!

Factors That Affect Barrier Thickness

- Distance, Occupancy, Control, Workload, Use Factor & kVp

Distance

- It depends on the distance between the source of radiation & the barrier

Occupancy

- The use of the area that is being protected
- *Rarely Occupied:* less shielding required

Time Occupancy Factor (T)

- Length of time that the area being protected is used

Control

- *Controlled Area:* an area occupied primarily by radiology personnel & patients
  - *Limits:* 100 mrem/week
  - Based on the annual recommended occupational dose limit of 5000 mrem/yr or 50 mSv/yr
- *Uncontrolled Area:* an area that can be occupied by anyone
  - *Limit:* 2 mrem/week
  - Based on the annual recommended dose limit for the public of 100 mrem/yr
- *Protective Barrier:* it should ensure that no individual will receive more than 2.5 mrem/hr

LEVELS OF OCCUPANCY THAT MAY BE ADJACENT TO X-RAY ROOM AS SUGGESTED BY THE NCRP

Occupancy	Area
Full	Work areas, living quarters, children's play areas & occupied space in nearby buildings
Frequent	Corridors, restrooms & patient rooms
Occasional	Waiting rooms, stairways, unattended elevators, janitors' closets & outside area

Workload (W)

- Product of the maximum mA & the number of x-ray examinations performed per week
- *Expressed in:* mAmin/week
- Busy, General Purpose X-ray Room: 500 mAmin/week
- Private Office: <100 mAmin/week

Use Factor (U)

- The percentage of time during which the x-ray beam is on & directed toward a particular protective barrier
- *Walls:* ¼
- *Floor:* 1
- *Room for Chest Radiography:* 1

- *Others:* 0

The use factor for secondary barriers is always 1!

kVp

- It is used as a measure of penetrability
- *General Radiography:* 100 kVp
- *Mammography:* 30 kVp

RADIATION DETECTION & MEASUREMENT

Radiation Detection Instrument

- Designed to detect or measure radiation
- Operate in the *pulse* or *rate* mode
    - It is used to indicate the presence of radiation

Pulse Mode

- The presence of radiation is indicated by ticking, chirping or beeping sound

Rate Mode

- The instrument response is expressed in mR/hr or R/hr

Integrated Mode

- It is used in instruments designed to measure the intensity of radiation

Dosimetry

- The practice of measuring the intensity of radiation

Dosimeters

- The radiation-measuring devices

Radiation Detection & Measuring Device

- Photographic, Ionization Chamber, Proportional Counter, Geiger-Muller Counter, Thermoluminescence Dosimetry, Optically-Stimulated Luminescence Dosimetry & Scintillation Detection

Photographic Emulsion

- The earliest radiation detection device
- *Characteristics:* limited range, sensitive & energy dependent
- *Uses:* personnel monitoring & emulsion imaging

Two Principal Applications of Film

- The making of a radiograph
- The radiation monitoring of personnel (film badge)

Gas-Filled Radiation Detector

- It is used widely as a device to measure radiation intensity & to detect radioactive contamination
- *Three Types:* ionization chamber, proportional counter & Geiger-Muller counter

The ionization of gas is the basis for gas-filled radiation detectors!

Ionization Chamber

- The instrument of choice for measuring radiation intensity
- *Characteristics:* wide range, accurate & portable
- *Uses:* survey for radiation levels 1 mR/hr

High sensitivity means that an instrument can detect very low radiation intensities!

High Level of Accuracy

- It means that an instrument can detect & precisely measure the intensity of radiation field

Instrument Accuracy

- Controlled by the overall electronic design of the device

Dose Calibrator

- Another application of precision ion chamber
- It is used in nuclear medicine laboratories for the assay of radioactive material

Proportional Counter

- It has the ability to distinguish between alpha & beta radiation
- *Characteristics:* laboratory equipment, accurate & sensitive
- *Uses:* assay of small quantities of radionuclides

Geiger-Muller Counter
- It is used for contamination control in nuclear medicine laboratories
- *Characteristics:* limited to 100 mR/hr & portable
- *Uses:* survey for low radiation levels & radioactive contamination

Resolving Time
- The minimum time between ionizations that can be detected

Quenching Agent
- Added to the filling gas of the Geiger counter to enable the chamber to return to its original condition

Thermoluminescence Dosimetry (TLD)
- *Characteristics:* wide range, accurate & sensitive
- *Uses:* personnel monitoring, stationary & area monitoring

Optically Stimulated Luminescence Dosimetry
- *Characteristics:* wide range, accurate & sensitive
- *Uses:* newest personnel monitoring device

Scintillation Detection
- Basis for the gamma camera
- It is used in the detectors arrays of CT imaging system
- It is used as IR in digital imaging system
- *Characteristics:* limited range, very sensitive, & stationary or portable instruments
- *Uses:* photon spectroscopy & imaging

Gamma Camera
- An imaging device used in nuclear imaging
- It is also used in CT & DR imaging system

Liquid Scintillation Detectors
- It is used frequently to detect low-energy beta emission from carbon-14 & tritium

Types of Scintillation Phosphors
- Thallium-activated sodium iodide (NaI: Tl)
  - Incorporated into gamma camera
- Thallium-activated cesium iodide (CsI: Tl)
  - Incorporated into image-intensifier tubes as the input phosphor & into flat panel DR image receptors

The Scintillation Detector Assembly
- Aluminum Seal, Window, Photocathode, Dynodes, Glass Envelope, Collector & Base

Aluminum Seal
- It allows the light flash to be reflected internally to the window
- It also necessary to seal the crystal hermetically

Window
- The portion of the glass envelope that is coupled to the scintillation crystal

Hermetic Seal
- One that prevents the crystal from coming into contact with air or moisture

Hygroscopic
- It absorbs moisture

Photomultiplier (PM) Tube
- It converts light flashes from the scintillator into an electronic signal of pulses

Glass Envelope
- It provides structural support for the internal elements & maintains the vacuum inside the tube

Photocathode

- A device that emits electrons when illuminated
- *Composition:* cesium, antimony & bismuth

Photoemission

- A process wherein electrons are emitted from the photocathode

Dynodes

- The first series of plate-like elements
- *Function:*
    - Amplify the electron pulse through secondary electron emission

Dynode Gain

- The ratio of secondary electrons to incident electrons

Photomultiplier Tube Gain

- The dynode gain raised to the power of the number of dynodes
- *Formula:* PM Tube = g^n

Collecting Electrode/Collector

- The last plate-like element of the PM tube
- *Functions:*
    - Absorbs the electron pulse from the last dynode
    - Conducts it to the preamplifier

Preamplifier

- It provides an initial state of pulse amplification

Base

- A structure that provides support for the glass envelope & internal structures

The size of the electron pulse is proportional to the energy absorbed by the crystal from the incident photon!

Gamma Spectrometry

- It uses pulse height analysis

Thermoluminescence Dosimetry (TLD)

- The emission of light by a thermally stimulated crystal following irradiation
- *Step Process:*
    - Exposure to ionizing radiation
    - Subsequent heating
    - Measurement of the intensity of emitted light
- *Materials:* Lithium Fluoride, Calcium Fluoride, Lithium Borate & Calcium Sulfate
- *Advantages:*
    - Size
    - Reusable
    - Responds proportionately to dose
    - Rugged

Lithium Fluoride

- Commonly used
- *Symbol:* LiF
- *Density 10^3 (kg/m^3):* 2.64
- *Effective Atomic Number:* 8.2
- *Temperature of Main Peak (^{o}C):* 195
- *Principal Use:* patient & personnel dose
- *Characteristic:* sensitive
    - as low as 5 mrad
    - >10 rad
- *Accuracy:* better than 5%

Lithium fluoride is a nearly tissue-equivalent radiation dosimeter!

Calcium Fluoride Activated with Manganese

- *Symbol:* CaF_2:Mn
- *Density 10^3 (kg/m^3):* 3.18
- *Effective Atomic Number:* 16.3
- *Temperature of Main Peak (^{o}C):* 260
- *Principal Use:* environmental monitoring
- *Characteristic:* more sensitive
    - < 1 mrad

Lithium Borate

- *Symbol:* $Li_2B_4O_7$:Mn
- *Density 10^3 (kg/m^3):* 2.5
- *Effetive Atomic Number:* 7.4
- *Temperature of Main Peak (^{o}C):* 200
- *Principal Use:* research

Calcium Sulfate

- *Symbol:* $CaSO_4$:Dy
- *Density 10^3 (kg/m^3):* 2.61
- *Effetive Atomic Number:* 15.3
- *Temperature of Main Peak (^oC):* 220
- *Principal Use:* environmental monitoring

TLD Analyzer

- Electronic instruments that are designed to:
    - Analyzed measure the height of the glow curve
    - The area under the curve
    - Relate this to exposure or dose through a convention factor

Glow Curve

- Graph that shows the relationship of light output to temperature change

Optically Stimulated Luminescence Dosimetry (OSL)

- Developed by Laundauer in late 1990s
- *Material:* Aluminum oxide (Al_2O_3)
- *Step Process:*
    - Exposure to ionizing radiation
    - Laser illumination
    - Measurement of the intensity of stimulated light emission
- *Advantages Over TLD:*
    - More sensitive – 1 mrad
    - Reanalysis
        - Confirmation of dose
        - Qualitative information about exposure conditions
    - Wide dynamic range
    - Excellent long-term stability